

Optically Controlled Phased Array Antenna Concepts Using GaAs Monolithic Microwave Integrated Circuits

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Richard R. Kunath and Kul B. Bhasin
Lewis Research Center
Cleveland, Ohio

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OPTICALLY CONTROLLED PHASED ARRAY ANTENNA CONCEPTS USING GaAs
MONOLITHIC MICROWAVE INTEGRATED CIRCUITS

Richard R. Kunath and Kul B. Bhasin
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

ABSTRACT

The desire for rapid beam reconfigurability and steering has led to the exploration of new techniques. Optical techniques have been suggested as potential candidates for implementing these needs. Candidates generally fall into one of two areas: those using fiber optic Beam Forming Networks (BFNs) and those using optically processed BFNs. Both techniques utilize GaAs Monolithic Microwave Integrated Circuits (MMICs) in the BFN, but the role of the MMIC for providing phase and amplitude variations is largely eliminated by some new optical processing techniques. This paper discusses these two types of optical BFN designs and provides conceptual designs of both systems.

INTRODUCTION

The advantages of using large direct radiating phased arrays for rapid beam scanning are well known. However, conventional techniques for implementing large phased arrays have resulted in heavy, high loss distribution systems. MMICs have offered the ability to have a low loss distribution system that has graceful degradation. Still, the interconnection of many MMIC modules poses formidable topology, EMI, and crosstalk problems.

In an effort to utilize the advantages of MMICs, new BFN techniques have been proposed. These techniques employ optical components not only to distribute signals, but also to form the phase and amplitude distribution. Two general categories of optically controlled GaAs MMIC-based array antennas have been identified. Those systems using fiber optic BFNs and those using optically processed BFNs are discussed in this paper. Conceptual diagrams of both fiber optic and optically processed BFNs are shown in Figs. 1 and 2, respectively.

FIBER OPTIC BFNs

Several concepts for using fiber optics in antenna applications can be found in the literature (Refs. 1 and 2). This paper will consider only those applications that use the fiber as an optical transmission line. In this type of system, the GaAs MMIC is complex; it is equipped with variable phase shifters (VPSs) and variable power amplifiers (VPAs) to create an array aperture with the appropriate phase and amplitude distribution. The optical fiber is used for interconnection and offers mechanical flexibility, low

loss, lightweight, minimum crosstalk, and greatly diminished EMI to the BFN.

The use of fiber interconnection is critical when large, lightweight arrays are being considered. The inherently large bandwidth of fiber allows it to carry multiple signals of both RF and data. A more complete description is given by Bhasin, et al. (Ref. 3). It is important that the MMIC module to which the fiber is connected be small and lightweight for large packing densities, an even more important consideration is the design of the module/fiber connection. When large arrays are considered, the module must be accessible from the back, because fiber connection to the edge limits the array size. A conceptual drawing of an MMIC module is given in Fig. 3. A block circuit diagram of an optical integrated circuit being developed under a NASA contract is shown in Fig. 4. Table I gives a list of characteristics for fiber optic BFNs.

OPTICALLY PROCESSED BFNs

The use of optical processing components to obtain the desired amplitude and phase distribution is the basis for this type of system. This technique is realizable because the antenna far-field pattern (FF) is the Fourier Transform (FT) of the antenna's near-field (NF) distribution, and two optical signals can be mixed to produce a microwave difference frequency. By using optical processing components, a two-dimensional FT can be performed in realtime by the FF diffraction of coherent light (Ref. 4). As suggested by Koepf, the antenna NF phase and amplitude distribution is created by forming an optical version (image mask) of the desired antenna FF pattern with coherent light. After passing this signal through a FT lens and mixing it with a second coherent optical (reference) signal whose frequency is different by the frequency of the desired microwave carrier, an optical phase and amplitude distribution at the desired microwave carrier frequency is produced. This distribution is then sampled by a fiber optic array and the resulting optical signals are carried to remote MMIC amplifiers in a microwave antenna array. A more detailed description and some preliminary experimental results can be found in Ref. 5.

The complexity of the MMIC device in this type of system is greatly reduced. The MMIC requires no VPS or VPA; the only function necessary is constant gain amplification. This eliminates the need for MMIC control lines. Instead, the conversion efficiency of the optical demodulator and noise level of the amplifier are the primary concerns. In addition, this system exhibits some unique properties for magnification and spatial sampling. Table I gives a list of characteristics for optically processed BFNs. NASA is funding a Hughes Aircraft Company study to investigate this concept.

CONCLUSIONS

Two general approaches for using optical techniques for creating BFNs have been presented. These techniques exploit

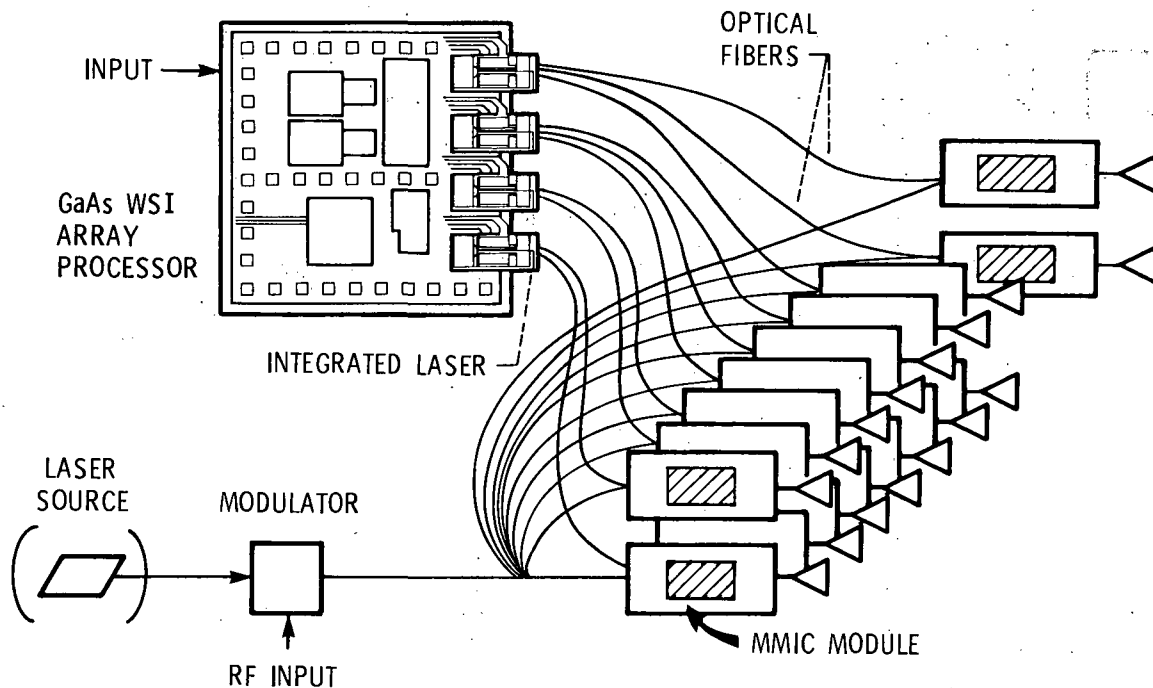
different attributes of optical components. In general, these techniques fall into one of two categories: those that use fiber optic cables for signal distribution only and those that use various optical components (FT lenses, fiber optic arrays, and image masks) to create the antenna NF phase and amplitude distribution. Both techniques require the use of MMICs, however, the latter does not require a complex MMIC having VPSs and VPAs. As the development of optical components continues, and as array element numbers and frequencies get higher, either or both of these types of systems could provide for developing large, lightweight, rapidly reconfigurable, and steered phased array antennas.

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TABLE I. - CHARACTERISTICS OF OPTICALLY CONTROLLED BFNS

Fiber optic BFNs	Optically processed BFNs
<ul style="list-style-type: none"> • Lightweight, high density distribution system • High speed data transmission • Reduced crosstalk and EMI • High reliability due to monolithic integration • Allows interface to optical processing • Higher level of power consumption 	<ul style="list-style-type: none"> • Uses simplified MMIC • Creates NF distribution using optical image mask • Continuously adjustable beam steering • Unique magnification and sampling capabilities • Requires critical optical processing component development



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Figure 1. - Optically controlled and FED monolithic IC's for phased array antenna.

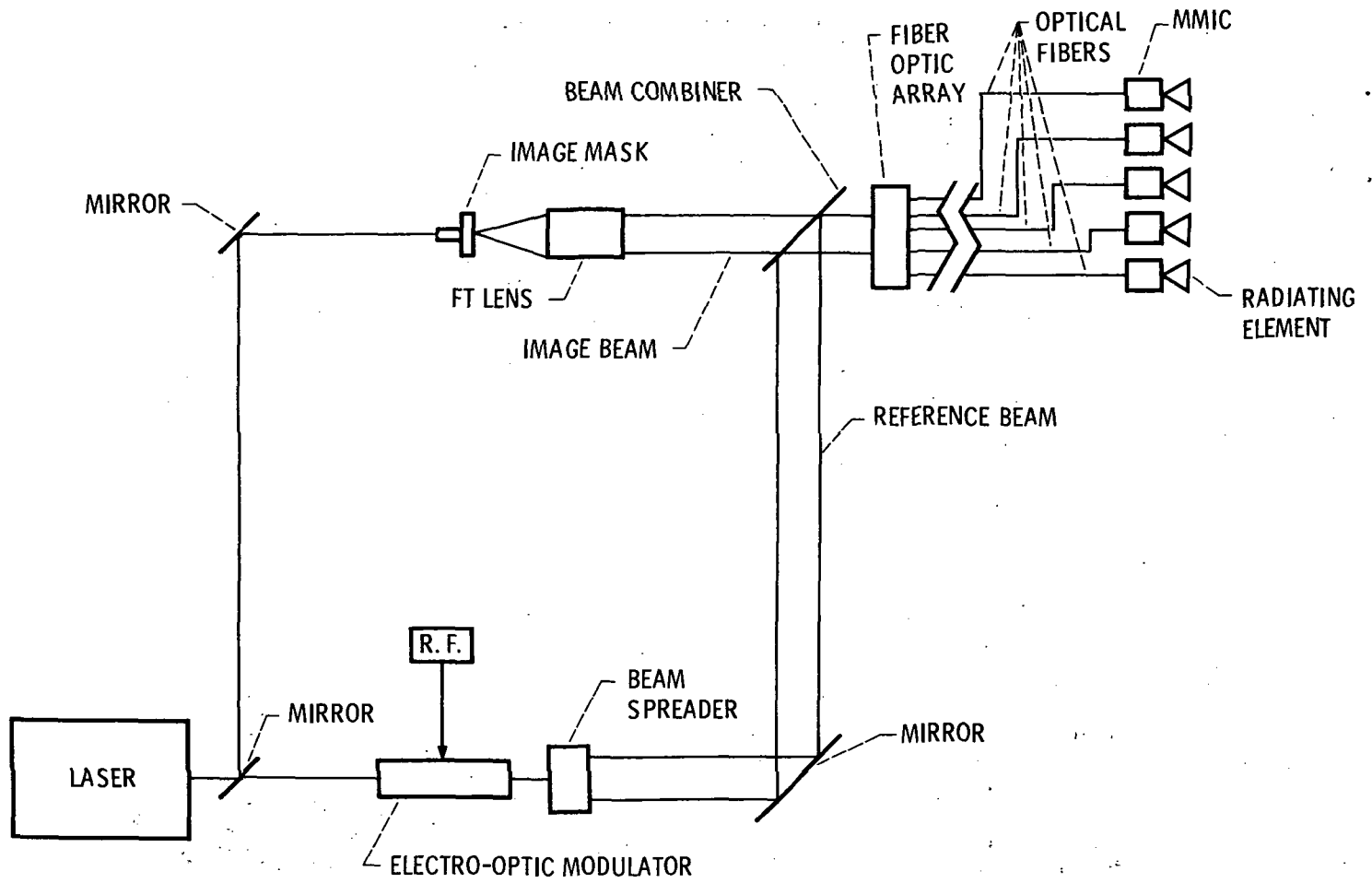


Figure 2. - Optically processed beam forming network.

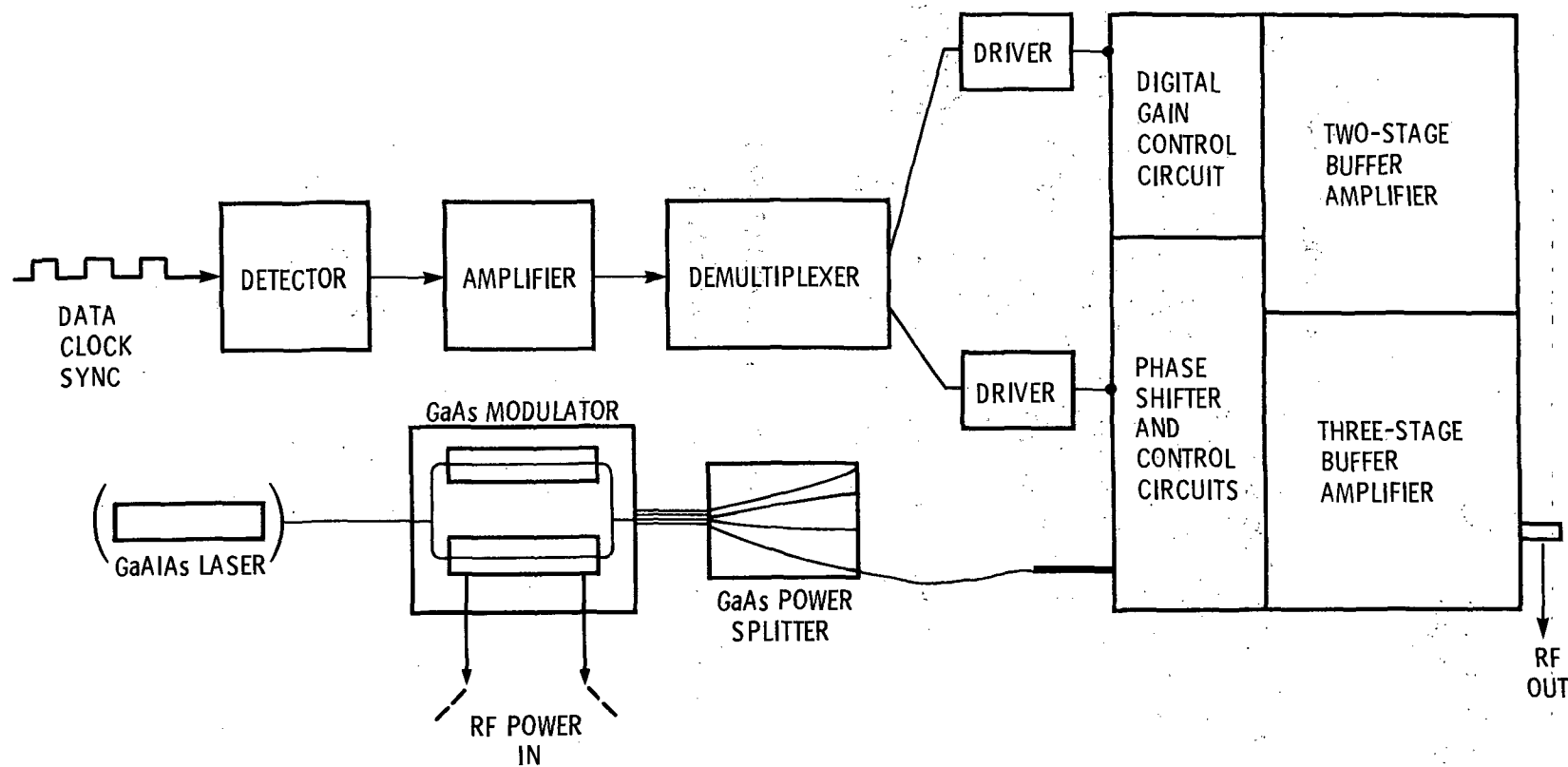


Figure 3. - Block circuit diagram of optical/MMIC interface.

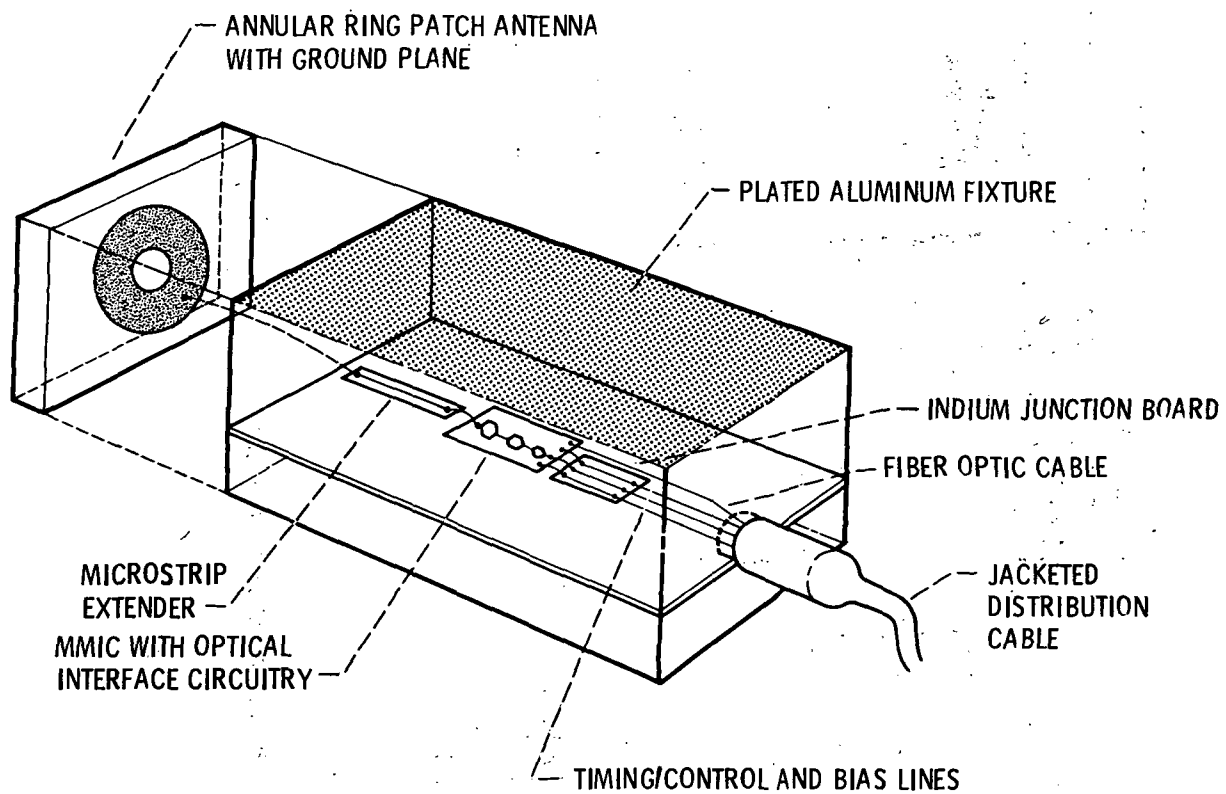


Figure 4. - MMIC module with fiber optic interconnection.

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